Technology Insertion and Management:
Options for the Canadian Forces

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Abstract

Growing interest among Canada's allies in the field of Technology Insertion suggests a paradigm shift is underway in the way in which militaries develop and employ technology for use with their defence systems. Drivers such as a dynamic future security environment, rapid technological innovation and rising unit cost growth can significantly erode the combat effectiveness of deployed systems over the length of their lifecycle. Achieving optimal through-life capability effectiveness, lowered costs of ownership and a minimized risk of system obsolescence are three primary goals for which Technology Insertion can be optimized. This Technical Memorandum investigates the theoretical concepts of Technology Insertion, its practice among Canada's allies and, finally, provides some methodological tools necessary for an optimization-based, cost-benefit analysis of Technology Insertion options.

Résumé

L'intérêt croissant des alliés du Canada pour l'insertion technologique semble indiquer qu'un changement de paradigme est en cours dans la façon dont les militaires élaborent et emploient la technologie à utiliser avec leurs systèmes de défense. Des facteurs, tels qu'un futur environnement de sécurité dynamique, l'innovation technologique rapide et la progression des coûts unitaires, peuvent éroder considérablement l'efficacité au combat des systèmes déployés au cours de la durée de leur cycle de vie. L'atteinte de l'efficacité optimale des capacités sur la durée de vie, la baisse des coûts de propriété et une limitation du risque d'obsolescence des systèmes sont trois des principales raisons pour lesquelles on peut optimiser l'insertion technologique. Le présent document étudie les concepts théoriques de l'insertion technologique et son utilisation parmi les alliés du Canada et fournira certaines méthodes qui sont nécessaires pour faire une analyse coûts-avantages fondée sur l'optimisation des options en matière d'insertion technologique.

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Executive summary

Technology Insertion and Management: Options for the Canadian Forces

Mike Stocker; DRDC CORA TM 2010-015; Defence R&D Canada – CORA; January 2010.

Growing interest among Canada's allies in the field of Technology Insertion (TI) suggests a paradigm shift is underway in the way in which militaries develop and employ technology for use with their defence systems. Drivers such as a dynamic future security environment, rapid technological innovation and rising unit cost growth can significantly erode the combat effectiveness of deployed systems over the length of their lifecycle. Achieving optimal through-life capability effectiveness, lowered costs of ownership and a minimized risk of system obsolescence are three primary goals for which Technology Insertion can be optimized.

In seeking greater knowledge about the concept of Technology Insertion and how it relates to the activities and interests of the Department of National Defence (DND) and the Canadian Forces (CF), Defence Research and Development Canada (DRDC) tasked the Centre for Operational Research and Analysis (CORA) with preparing an exploratory study of the subject.

The following Memorandum entitled "Technology Insertion and Management: Options for the Canadian Forces" is a strategic-level, qualitative literature review of the Technology Insertion concept and its suitability for adoption by the Canadian Forces (CF). The goal of this initial project was four-fold: (1) to develop a theoretical understanding of technology insertion; (2) to develop an appreciation of the enablers and impediments to operationalizing technology insertion; (3) to seek out "best practices" derived from work already undertaken by some of Canada's key allies; and (4) to identify cost-benefit criteria and methodologies necessary for a rigorous assessment of TI proposals.

Within the military and defence community, a generic definition which captures the essence of the Technology Insertion philosophy has emerged after much debate. TI should now be understood as *the utilization of a new or improved technology in an existing product*. TI refers to the "refreshment" and "enhancement" of system performance and functionality in existing or deployed defence systems by the utilization of a new or improved technology. Importantly, TI in defence systems can occur in the vertical space—which constitutes components, equipment, sub-system, and the system level—and the horizontal space—which finds common solutions to similar but distinct weapons platforms, such as land systems.

As a mechanism for managing system or sub-system obsolescence, to reduce "costs of ownership" associated with a particular defence system or, as we are primarily concerned with in Canada, to maintain or enhance a system's capabilities and unit-force effectiveness throughout its lifecycle, the concept of Technology Insertion does indeed hold some promise. While barriers and impediments to effective TI implementation do remain (such examples include but are not limited to, a risk-adverse defence bureaucracy, or misaligned incentives for defence contractors) the CF seem well positioned to avoid some of the more intractable challenges which others countries do face, owing in part to the recent adoption of a Capability-Based Planning (CBP) process by the

CF and the entrenched structure of our unified armed forces. In fact, force development under CBP stands to benefit from greater integration of the TI concept with the Evolutionary Acquisition (EA) approach. This is so because EA seeks to deliver capabilities in increments and in full recognition of the need for future improvements in future capability. TI and its associated technology management mechanisms seem ideal for facilitating future upgrades where end-state requirements may (but more likely may not) be known.

As our allies' experience with nascent TI programs demonstrates, substantial gains in terms of greater operational currency and a reduced logistical burden are possible if technology insertion is effectively implemented. Curtailing the costs of ownership of a particularly burdensome defence system represents the "low-hanging fruit" which can likely be attained with moderate effort. Optimizing technology insertion for this purpose ought to be considered a strong candidate for the first of any future pilot project in TI.

The goals of the study (described above) did not prove exceedingly onerous and produced findings that were not unexpected by its author (despite significant gaps in the existing literature). First, the study was able to develop a theoretical understanding of the concept of Technology Insertion despite definitional issues, which defined the "space" (the depth and breadth of the issue) for which Technology Insertion activities can and do occur. Second, the study provided a rigorous rationale for Technology Insertion implementation as well as provided a full discussion as to the main barriers and enablers to effective Technology Insertion. Third, and in keeping with the strategic nature of the document, the study offered some "best practice" case study-type examples provided by the extensive work already carried out by our U.S. and U.K. allies in the field of Technology Insertion. Finally, the study provided a variety of methodological tools necessary for an optimization-based cost-benefit analysis of Technology Insertion options. With regard to this final point, Phase II of this study will seek to develop a business case for potential CF pilot projects by applying more sophisticated technologies to the existing models described herein.

Sommaire

Technology Insertion and Management: Options for the Canadian Forces

Mike Stocker; DRDC CORA TM 2010-015; R & D pour la défense Canada – CORA; Janvier 2010.

L'intérêt croissant des alliés du Canada pour l'insertion technologique semble indiquer qu'un changement de paradigme est en cours dans la façon dont les militaires élaborent et emploient la technologie à utiliser avec leurs systèmes de défense. Des facteurs, tels qu'un futur environnement de sécurité dynamique, l'innovation technologique rapide et la progression des coûts unitaires, peuvent éroder considérablement l'efficacité au combat des systèmes déployés au cours de la durée de leur cycle de vie. L'atteinte de l'efficacité optimale des capacités sur la durée de vie, la baisse des coûts de propriété et une limitation du risque d'obsolescence des systèmes sont trois des principales raisons pour lesquelles on peut optimiser l'insertion technologique.

Dans sa recherche visant à mieux comprendre le concept de l'insertion technologique et sa relation avec les activités et les intérêts du ministère de la Défense nationale (MDN) et des Forces canadiennes (FC), Recherche et développement pour la Défense Canada (RDDC) a confié la tâche de faire une étude préliminaire de la question au Centre d'analyse et de recherche opérationnelle (CARO).

L'étude intitulée « L'insertion technologique et la gestion de la technologie : Options pour les Forces canadiennes », est une analyse documentaire qualitative de niveau stratégique du concept de l'insertion technologique et de la pertinence de son adoption par les Forces canadiennes. Le projet initial avait un objectif à quatre volets : 1) acquérir une compréhension théorique de l'insertion technologique, 2) élaborer une appréciation des outils et des obstacles en matière d'opérationnalisation de l'insertion technologique, 3) rechercher les « meilleures pratiques » provenant des travaux déjà entrepris par certains des principaux alliés du Canada et 4) définir les critères de rentabilité ainsi que les méthodes nécessaires à une évaluation rigoureuse des propositions relatives à l'insertion technologique.

De longues discussions au sein de la collectivité militaire et de la défense ont abouti à une définition générique qui saisit l'essence de la philosophie de l'insertion technologique. On doit maintenant sous-entendre par cette expression *l'utilisation d'une technologie nouvelle ou améliorée dans un produit existant*. L'insertion technologique désigne la « modernisation » ou l'« amélioration » du rendement et de la fonctionnalité d'un système de défense existant ou déployé par l'utilisation d'une technologie nouvelle ou améliorée. Fait important, l'insertion technologique dans les système de défense peut se présenter dans l'espace vertical – que constitue le niveau des composantes, du matériel, du sous-système et du système – et dans l'espace horizontal – qui trouve des solutions communes à des plateformes semblables, mais distinctes, telles que les systèmes terrestres.

En tant que moyen de gérer l'obsolescence des systèmes ou des sous-systèmes, de réduire les « coûts de propriété » associés à un système de défense particulier ou, ce qui nous intéresse le plus au Canada, de maintenir ou d'améliorer les capacités d'un système et l'efficacité de l'unité/la

force pendant son cycle de vie, le concept de l'insertion technologique est vraiment prometteur. Même s'il reste encore des obstacles à la mise en œuvre efficace de l'insertion technologique (mentionnons à titre d'exemples, entre autres, une bureaucratie de la défense hostile au risque ou des mesures d'incitation mal alignées pour les entrepreneurs de la défense), les FC semblent bien placées pour éviter certains des problèmes les plus ardus avec lesquels d'autres pays sont aux prises, et ce, en partie parce qu'elles ont adopté récemment le processus de planification fondée sur les capacités (PFC) et en raison de la structure des forces armées unifiées qui est en place. En fait, le développement des forces dans le cadre de la PFC devrait retirer des avantages d'une meilleure intégration du concept de l'insertion technologique et de l'approche de l'acquisition évolutive, parce que l'acquisition évolutive cherche à fournir des capacités par ajout et en reconnaissant pleinement la nécessité d'apporter des améliorations ultérieurement à la capacité future. L'insertion technologique et les mécanismes de gestion de la technologie qui y sont associés semblent idéals pour faciliter les améliorations futures dans les cas où les exigences relatives à l'état final seraient connues (ou plus probablement ne le seraient pas).

Comme le montre l'expérience des nouveaux programmes d'insertion technologique de nos alliés, il est possible de faire des gains substantiels du point de vue de l'augmentation de la fiabilité opérationnelle et de la diminution du fardeau logistique si l'insertion technologique est mise en œuvre de façon efficace. La réduction des coûts de propriété d'un système de défense particulièrement compliqué représente le « fruit mûr » qui peut probablement être atteint très facilement. L'optimisation de l'insertion technologique à cette fin devrait être considérée comme un bon candidat dans le choix du premier des futurs projets pilotes en insertion technologique.

Les objectifs de l'étude (décrite ci-dessus) ne se sont pas révélés extrêmement onéreux et ont produit des conclusions auxquelles l'auteur s'attendait (en dépit de manquements importants dans la documentation existante). En premier lieu, l'étude a permis d'élaborer une compréhension théorique du concept de l'insertion technologique malgré des problèmes définitionnels, qui a défini l'« espace » (la profondeur et l'étendue de la question) pour lequel les activités d'insertion technologique peuvent survenir et surviennent effectivement. En deuxième lieu, elle a fourni une justification rigoureuse de la mise en œuvre de l'insertion technologique et a permis d'examiner de façon approfondie les principaux obstacles et outils liés à l'insertion technologique efficace. Troisièmement, et conformément à la nature stratégique du document, elle a offert des exemples de type « étude de cas » des meilleures pratiques tirées des travaux d'envergure déjà effectués par nos alliés des États-Unis et du Royaume-Uni dans le domaine de l'insertion technologique. Enfin, elle a fourni une gamme de méthodes nécessaires à une analyse coûts-avantages fondée sur l'optimisation des options en matière d'insertion technologique. Pour ce qui est de ce dernier point, la phase II de l'étude cherchera à élaborer une analyse de rentabilisation concernant des projets pilotes possibles des FC en appliquant des techniques plus avancées aux modèles existants décrits aux présentes.

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1 Introduction

1.1 Background

Technology Insertion (TI) has now become an area of major interest for the Western defence community. For example, in 2004 the U.K. launched TI-MPA, the Technology Insertion Major Program Area, a Ministry of Defence (MOD) sponsored research program intended to facilitate TI use and so allow the MOD to improve its use of technology in its military equipment. In 2005, the U.K. released its Defence Industrial Strategy which stated that the future business model for the defence industry will be on the support and upgrade of products that are currently in the inventory of forces. [1] The focus would now look toward “rapidly inserting technology to meet emerging threats, fulfill new requirements and respond to innovative opportunities” for its existing generation of equipment, as opposed to the design and manufacture of a next generation platform. Similarly, TI has been recognized as a prominent activity in the U.S. For example, the U.S. Air Force has adopted TI as a primary way to modernize its legacy aircraft fleet in order to retain technological superiority and capability effectiveness. [2] To this end, the U.S. Air Force spends US$2 billion per year on the effort, although the Department of Defense (DoD) concedes they need to do more to improve its processes for TI. [3]

Both examples from the U.S. and the U.K. demonstrate a recognition on behalf of defence planners that TI can offer significant capability benefits to their respective militaries. But what exactly constitutes technology insertion and how might its associated principles be applied more effectively in practice remains a matter of enduring debate.

While a variety of definitions has evolved over recent years to describe the rather esoteric concept of Technology Insertion, a broad consensual definition of the concept continues to elude the defence community. To some, technology insertion in defence systems refers to the attempt to manage system or sub-system obsolescence; others view TI as a means to reduce the “costs of ownership” associated with a particular system; still others see TI as being primarily useful in maintaining or enhance a system’s fighting capabilities and overall unit-force effectiveness through the entirety of its system life-cycle. In fact, effective technology insertion encompasses all the above, and has the potential to produce synergistic effects across these three dimensions.

Proponents of the technology insertion concept point to several factors which tend to mitigate or degrade unit-force capability and effectiveness. Firstly, the highly dynamic nature of the contemporary and future security environment requires that militaries be prepared to engage in operations across the entire spectrum of conflict, that is, from low-intensity humanitarian operations, to counterinsurgency campaigns and to high intensity conventional warfare. Second, militaries around the world are seeking ways in which to capitalize on the rapid pace of technological innovation in the civilian sector for use in defence systems. And finally, owing to budgetary pressures within both the government in general and the defence bureaucracy in particular, there is an enduring pressure to “do more with less” as unit costs increase and real defence spending stagnates.

It is within this dynamic context that the following Memorandum examines the TI concept based on a literature survey of relevant government, military and industry documents to arrive at some general conclusions regarding the suitability of TI for the adoption by the Canadian Forces (CF),

with particular regards to capability optimization. As well, TI must be analyzed to determine its suitability to defence system procurement under the CF Capability Based Planning model. Finally, because one cannot simply assume that such technology strategies are appropriate for any and all militaries, we must be aware as to how Canada's unique characteristics such as geography, budget size and industrial base might limit or constrain efforts to adopt such a technology management strategy.

1.2 Scope and Objective

The following Memorandum is a strategic-level, qualitative literature review of the Technology Insertion concept and its feasibility for adoption by the Canadian Forces (CF). The goal of this initial project is to develop and demonstrate options for technology management that will assist in the seamless upgrade of Canadian Forces' capabilities. This Memorandum explores the TI concept and its constituent elements, while drawing on case studies of existing TI projects already underway. It is the objective of this Memorandum to identify some common facts about TI, and arrive at some tentative observations and recommendations for the CF. As well, this Memorandum explores some quantitative and qualitative cost-benefit criteria metrics for assessing TI suitability for adoption by the CF.

While a follow-on quantitative study will provide a business case with more varied and sophisticated statistical analysis methods into the relative cost-benefit relationship between TI-enabled and non-enabled systems, this Memorandum restricts itself to a literature review exercise that identifies the concepts and criteria by which a technology insertion project ought to be examined within the Canadian defence and security context.

1.3 Document Structure

The Memorandum is organized as follows. In the next section, the concept of technology insertion is explored by providing a discussion of its definition, components and operating environment. Following this, a generalized rationale for technology is offered within the context of various approaches to lifecycle management.A description of the obstacles to effective technology insertion is also explored. In the fourth section, an effort is made to place technology insertion within the Canadian context, with additional analysis as to how technology insertion strategies are being pursued among Canada's allies. The final section discusses the cost-benefit calculus associated with technology insertion with particular attention paid to various optimization approaches. The Memorandum concludes with some recommendations and areas deserving future research.

2 Technology Insertion: Definitions, Components, Dimensions

Before taking a more detailed look at technology insertion and its viability for adoption by the CF, we require a better sense of the philosophy of TI, that is, understanding its terminology, its constituent components and the space within which such activities can and do occur.

2.1 Defining Technology Insertion

A consensual definition of Technology Insertion (TI) has thus far tended to elude the broad defence community. This is most likely attributed to the focus in which different stakeholder groups—end users such as a military's various services, government bodies (defence departments) and industrial partners—seek to define the term. Accordingly, several definitions have emerged to describe the TI concept.

Kerr, Phal and Probert attempted to catalogue TI definitions from practitioner and documentary sources drawn primarily from the American and British literature and to a lesser extent from Europe, Australia and Canada. Based on their wide review of TI definitions [4] two common elements emerged: (i) the use of better technology; and (ii) a product in need of improvement. Using these two common elements, a new generic definition was generated for Technology Insertion: *the utilization of a new or improved technology in an existing product.* [5]

Importantly, the definition stresses the word "existing" as it equates to a post-delivery phase where the product is already fielded with a particular military end-user. An existing product can refer to both legacy systems which have been in operation for several years as well as to a relatively new system which might have just entered service. Therefore, regardless of how long the system has been in the field, as long as it is in the in-service phase of its product lifecycle, then technology insertion is an appropriate term to use. Technology Insertion is therefore a generic umbrella term that can encompass such descriptors as: modernization programs, capability development and sustainment service, capability upgrade program, continuous technology refresh, mid-life improvement, service life extension program and system enhancement program. This is far from an exhaustive list, but it does demonstrate the breadth of industry terminology that satisfies the TI concept.

2.2 Components of Technology Insertion

Based on the definition for TI, we can further break down the term to identify its conceptual components, which reflect two technical perspectives for the utilization of a new or improved technology. "Refreshment"—to maintain functionality, can be understood as the updating of technology to prevent obsolescence in an existing product. "Enhancement"—to upgrade functionality, can be understood as the upgrading of technology to enhance capability in an existing product. Importantly, it must be understood that technology insertion and its constituent elements reside within a broader set of technology management processes. Some fine distinctions do exist among technology insertion and various other technology processes (such as technology-development, -migration, -transfer, -transition, -adoption, -refreshment, -enhancement) but because we have already tightly specified a definition for TI—that is, we know what TI is and

now what it is not—such a thorough examination is unnecessary and is considered beyond the scope of this analysis.

2.3 Dimensions of Technology Insertion

Technology insertion can be further defined by understanding in what dimensions such an activity can occur. Fundamentally, technology insertion can occur in a vertical and horizontal space. Vertical technology insertion (VTI) encompasses such activity which can occur at all levels of a product, at the system, equipment and component level. [6] In this construct, the platform of the product is akin to a shell which encapsulates a hierarchy of system, sub-system and component level equipment. Consider the case of a helicopter where such a platform can be retrofitted with completely new mission avionics systems (system level VTI), or where an improved mission computer or automatic flight controller is inserted (equipment level VTI). An illustrative example is given by the U.S. Army effort to rebuild its fleet of CH-47D Chinooks into a new generation (CH-47F). Here an equipment level VTI strategy sees the Chinook getting more powerful Honeywell engines that improve fuel efficiency and enhance lift performance by 3900lbs. [7]

Horizontal technology insertion (HTI) refers to TI activities which span sector, product, project and organizational boundaries. [8] The view of the U.S. Army, for example, which claim to have already realized significant gains from HTI, sees HTI as the "application of common technology solutions across multiple systems to improve the war-fighting capability of the total force." [9] Such TI strategies allow the Army to make better use of its limited modernization funds, citing, for example, the Army's second generation forward-looking infrared (GEN II FLIR) technology. [10] As well, a common B-Kit has been inserted into several ground-based platforms, including: M1A2 SEP Abrams tank, M2A3/M3A3 Bradley Fighting Vehicle, M707 Knight Vehicle, M1114 Up-Armored and M1151 Next-Generation HMMWV, and the Stryker Reconnaissance and Fire Support Variants. [11] Similar examples are offered by the U.S. Navy, which has employed an HTI strategy in the case of the acoustic rapid commercial off-the-shelf insertion (A-RCI) sonar system, an upgrade to be installed across the entire submarine fleet of Los Angeles, Seawolf, Virginia and Ohio class boats. [12]

As was mentioned above, confusion regarding the precise definition of technology insertion can lead to an umbrella-like broadening of the concept. In practical terms this could lead to "activities creep," where technology insertion activities intrude into related though distinct military activities. For example, what were described earlier as components of technology insertion ("refreshment" and "enhancement") are related to but distinct from such activities as operational maintenance and support. It is important to understand this distinction because such "activities creep" would devalue the philosophy and concept of technology insertion and risk finding itself among other once- vaunted though ultimately discarded military concepts (as, for example the concept of "Transformation"). Unless specifically defined otherwise, technology insertion activities ought to be defined as narrowly as possible to ensure the concept maintains its currency and does not become co-opted for purposes other than the enhancement of capabilities, the mitigation of obsolescence risk and the minimization of logistical expense.

As well, use of the technology insertion concept should be restricted to discussions of existing, in-service military products and thereby eschew consideration for products which might be fielded at some point in the future. Use of commercial-off-the-shelf technology (COTS) and open system architectures (OA), while a common practice in effective technology insertion activities, is also

part of a broader approach to system design and acquisition, commonly referred to as complex or adaptive systems engineering. Therein, systems are designed to maximize the use of COTS and OA in the early design and development stages to facilitate future capability enhancements by way of technology insertion. As well, modularity is an often used concept to describe a system architecture which relies on easily and rapidly swappable mission kits where the goal is to enhance operation flexibility while minimizing the impact of swapping on the system design and performance. Modularity, by use of COTS and/or OA is thus an enabler of future technology insertion; it is not a technology insertion activity in and of itself.

3 The Rationale for Technology Insertion

This section discusses the basic rationale for Technology Insertion in defence systems. As well, it briefly discusses the “barriers to entry” of implementing an effective Technology Insertion program.

3.1 Technology Insertion and the Short Lifecycle Approach

The procurement of defence systems is a notoriously difficult business. Coupled with a dynamic threat and technological environment, traditional single-pass defence procurement processes seem ill-equipped to deal with non-linear, unpredictable requirements demand, typical of today’s military needs. Long-lead time procurement processes and infrequent life-cycle modernization intervals often result in the fielding of equipment which can become obsolete—both in component equipment and unit-force capabilities—upon delivery. Under a CBP process, a TI strategy could prove effective at ameliorating these diametric pressures by providing either an enhancement of existing capabilities or by introducing new ones at relatively lower cost with minimal design impact. A Technology Insertion rationale model, as depicted below in Figure 1, encapsulates the drivers which confound procurement and support planners.

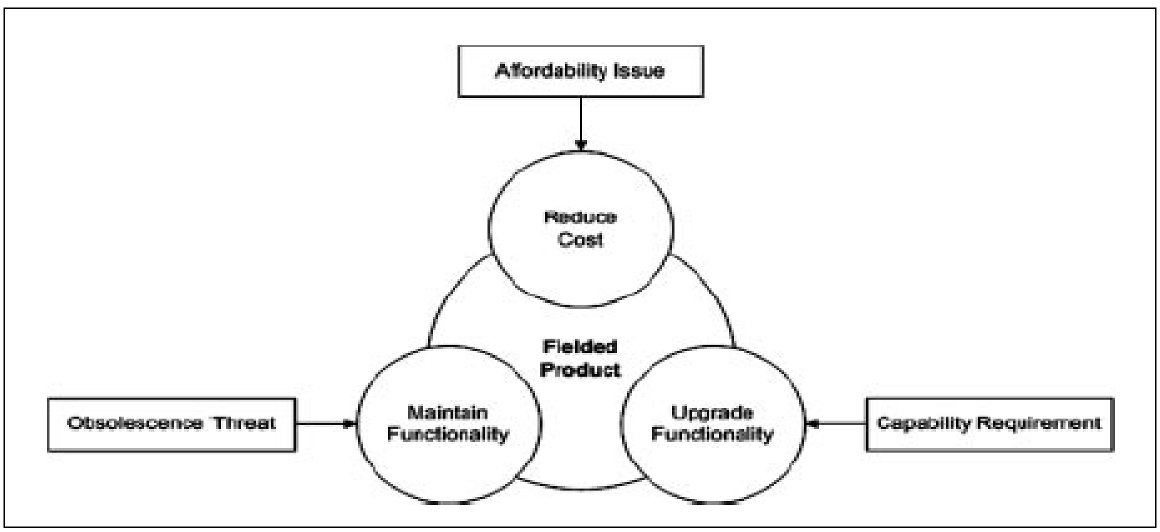

Figure 1 Technology Insertion Rationale Model. [13]

Capabilities Enhancement

The chief rationale for the adoption of a Technology Insertion program is that of the need to add on or enhance existing system capabilities in light of a new or changing threat scenario. A new or adapting threat, in turn, forces a change in operational requirements; therefore, a reorientation of system usage to meet the new threat must be undertaken to ensure some minimal level of performance. Technology Insertion offers the potential to rapidly adjust platform capabilities by employing internally developed technologies along a well thought out technology roadmap or by enlisting COTS and adapting them for military use. A capability based planning structure which supports a Short Lifecycle Acquisition (SLA or SL) evolutionary, spiral, or incremental strategy is best positioned to leverage the potential gains of subsystem technology insertion as capability upgrades are pre-planned and incorporated at the outset of a system's initial design and development stages.

The disadvantages of the tradition single pass acquisition approach is that the acquisition process can be so protracted that, by the time the system is delivered, it is at risk of meeting neither current customer requirements nor providing cutting edge capability (see Figure 2). Moreover, user and system requirements are fixed early in a system's lifecycle and, owing to the inflexibility of the procurement process, making even slight adjustments to those requirements becomes nearly impossible. The result then is a system whose performance remains at the same level—from an initial operational capability (IOC) which will decrease towards the end the lifecycle as reliability degrades—while the threat continues to evolve in both nature and capability. This can give rise to a capability gap either prior to or soon after a system is delivered. The only opportunity at adapting the system during its lifecycle may be at the mid-life update (MLU) point, where costs can be considerable and still results in a system having sub-optimal performance for a significant proportion of its lifecycle. [14]

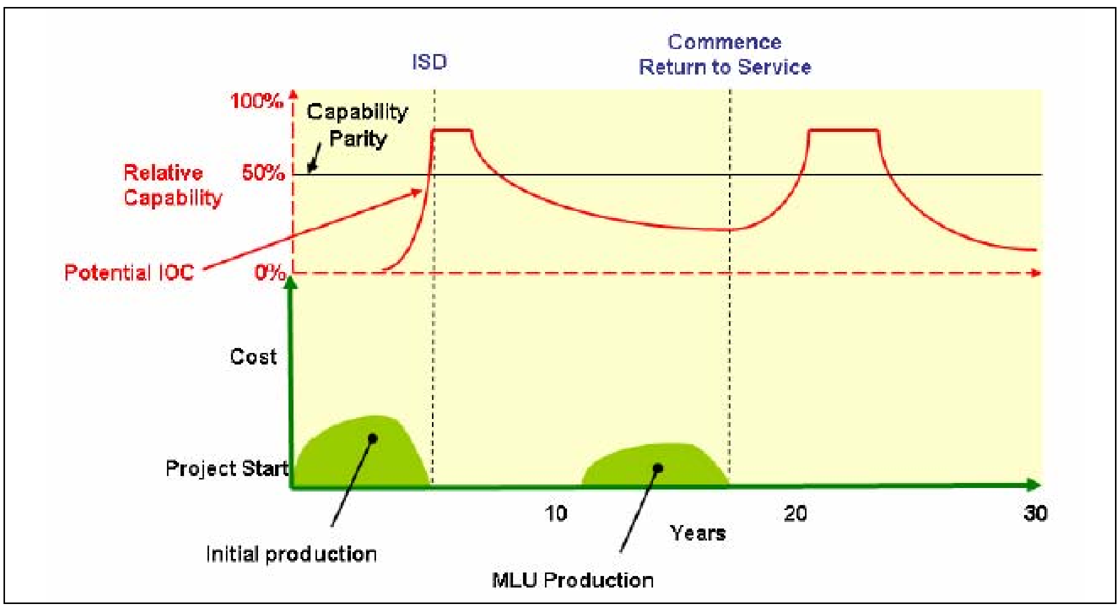

Figure 2 Relative Capability through life of system procured through traditional single-pass acquisition process.

In contrast to the traditional single pass approach, a system development and procurement using a Short Lifecycle approach can provide several intervals along a lifecycle where system adaptations can take place. While there still exist high levels of risks and uncertainty regarding technology maturity, system performance, etc., more frequent technology "refresh" intervals will theoretically produce an overall and through life capability which is much more closely aligned with actual customer requirements with a greatly reduced obsolescence risk (Figure 3). [15][16]

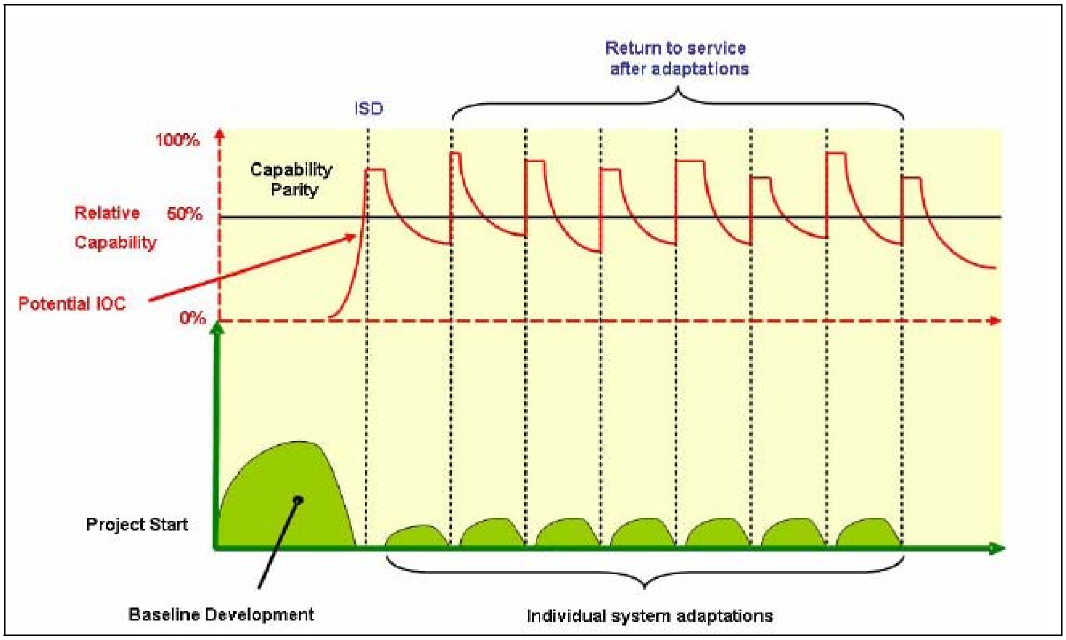

Figure 3 Relative Capability through life of system procured using Short Lifecycle Approach (SLA) with regular technology refresh intervals

System Obsolescence

Technology Insertion might also allow the military to respond more rapidly to the threat of system obsolescence, an often cited criticism of traditional procurement programs.[17] While technology obsolescence in consumer products is a desirable and ultimately productive process occurring over the course of a few short years, defence systems obsolescence is extremely hazardous to the war fighter and is derived primarily from its extremely long lifecycle, infrequent modernization intervals and relatively short production runs. Within those modernization intervals, a system's components will likely become unserviceable and unobtainable as defence contractors shut down old production lines and servicing contracts for which they may no longer have expertise or an economic interest. Stockpiling parts and maintaining and replacing electronics are the largest cost burdens of a system's operational maintenance and support budget. Rather than maintaining such a large logistics store, technology insertion permits the replacement of old system components with more capable and less costly alternatives giving the system a much higher level of capability adaptability and lowering obsolescence risks.

Obsolescence risk is also germane to the requirement for systems interoperability among allied countries. Without effective technology insertion, a country's ability to partake in coalition

operations is highly dubious. Moreover, as countries look to reduce manpower requirements by designing more technology-intensive systems, there is an ever-increasing tendency to utilize the latest mature technologies available. Militaries like the U.S. will be more likely to eschew interoperability limitations if it means getting better overall performance. It is then incumbent upon smaller allied militaries to keep up with the technology employed by the strongest military, so as to preserve some degree of interoperability. Requirements for interoperability with other systems can and do change, as other projects evolve or protocols change; therefore, some of these cases may be predicable while other may not. A Short Lifecycle approach with regular technology insertion points enhances overall system adaptability, which leaves the system better positioned to adapt to changing future requirements.

Costs of Ownership

Technology Insertion has the potential to reduce the through life costs of ownership associated with the operational maintenance and support regime of a particular defence system. Indeed, a primary driver of the technology insertion concept is the desire to reduce these lifecycle costs by inserting cost-reducing technologies to improve reliability and maintainability of military platforms. As explained by a U.S. DoD report on the subject [18], expected future costs can be curtailed by redirecting back into the operating and maintenance budget the savings in operating costs derived from an effective technology insertion program. Employing a "return on investment" metric, where a dollar invested returns some multiple (found to be between 3 and 20, over 20 years of that initial investment) in savings, provides convincing evidence to support a cost-reducing technology insertion strategy. While a TI strategy may have significant short-run or upfront costs, the payoff is in reduction of total ownership costs of the system, in the long run. However, it is important to note that these potential returns on investment savings are just that, and cannot be relied upon exclusively to bring down the total cost of ownership. Significant challenges exist in establishing an effective incentive structure, which will induce those units responsible for operational maintenance and support (OMS) to invest resources in cost-reducing technologies.

3.2 Barriers to Technology Insertion

A number of defence reports on Technology Insertion have identified several challenges and obstacles that need to be overcome for an effective utilization of a Technology Insertion strategy. [19] Beyond the purely technical challenges, which are of great significance but beyond the scope of this study, many of the obstacles originate from within the defence bureaucracy and from its relationships with industry.

Bureaucratic Constraints

Without delving too deeply into a debate over domestic procurement reform, bureaucratic and organization behaviours surrounding major weapons system management can negatively impact the lifecycle cost and performance of a system. A general tendency toward "short-termism" and "stove-piping," whereby the procurement organization and the concerned Service focus more attention and resources on the procurement phase (short-term needs) and less on the R&D and lifecycle management phase (long-term needs), takes attention away from that critical activity of maintaining and adapting system capabilities. Aggravating this tendency further are structural constraints such as "budget fencing" where administrators are prevented from tapping small

amounts of money from a variety of pools. As well, there is the glaring absence of a proper incentive structure to induce operational maintenance and support depots to develop and implement cost-saving plans through Technology Insertion. Such OMS units are best positioned to advise on the implementation of cost-reducing technology with regards to the maintenance and support of defence systems. Other potential solutions have been offered, including the creation of a Technology Insertion Account, which would blend R&D, procurement and OMS funds and thereby cut through any remaining budget fences. As well, appointing a “Systems Architect” position with broad budgetary powers who would be responsible for the through life management of Technology Insertion tradeoffs, would be an effective decision. Bureaucratic myopia and a generally risk-adverse attitude, either in the technology which the military wishes to employ or in the processes under which it procures for defence, work against any flexibility the procurement system may have. If building to maximize system flexibility and adaptability, which technology insertion facilitates, the organizational culture of the bureaucracy can impede progress as much as requirements and technology volatility do.

Defence Industrial Base

The relationship between a nation’s defence industrial base, its major contractors and system life-cycle management is another area needing attention to facilitate an effective Technology Insertion strategy. Declining defence budgets, fewer major system procurements and longer system life-cycle requirements imply a more variable future revenue stream for the prime contractors. However, the prime contractors need to be convinced that a TI strategy means more service contracts for those platforms which, for example, undergo a service life extension program. And because incremental enhancement is cheaper than the platform replacement, a staged introduction of new technologies throughout the life-cycle of a platform can greatly reduce the risk involved in introducing large improvements in a single step by allowing the progressive incorporation of evolving technology as it becomes available. This process, whereby state-of-the-art technologies are inserted continuously into weapon systems, can increase system and subsystem reliability, lower sustainment costs and increase unit-force effectiveness to meet evolving military requirements throughout an indefinite service life.

Designing for system adaptability through effective Technology Insertion will also require still greater collaboration with the defence bureaucracy and other industrial partners. [20] Several options exist for enhancing customer-supplier involvement, a key enabler of effective through-life technology management. One such mechanism to consider is to follow a commercial trend whereby customers contract for the procurement of services or capability rather than building toward tightly specified requirements. By offering a more attractive contract proposal, one which combines the new platform build with associated life-cycle support activities in a single fixed-price gains-plus contract, the supplier will be more willing to invest in maintaining relevant internal expertise and capability and will benefit financially if it develops improvements to performance, reliability or cost reduction. This approach rewards risk management and value rather than pure volume and is indicative of an effective incentive structure. Past policies of transferring as much risk as possible to the supplier without financial recognition pushes suppliers to follow a low risk technology strategy (that is, using pre-existing or mature rather than near mature technologies) which can produce sub-optimal supplier relations and, ultimately, sub-optimal system performance.[21] There is therefore a crucial need to shift the supplier-customer paradigm away from risk-aversion towards one of greater openness and long-term partnering.

What then is the cumulative effect of these barriers to effective technology insertion? From a purely theoretical standpoint, several of the aforementioned barriers do pose a challenge but they are not insurmountable. For example, DND has demonstrated an ability to adapt bureaucratic processes according to changes in the fiscal environment and the international security environment. DND's recent embrace of the capabilities based planning process is a cogent example of this. Moreover, the CF is better positioned than other militaries in terms of avoiding the tradition pitfalls of "stove-piping" as the unification of the Armed Forces in the 1960s [22] produced a common support structure that enforced fairly centralized resource management across the military.[23] This effort, coupled with a capabilities based approach to procurement, goes some distance in removing the incentives for service-centric procurement which was typical of the then threat based planning process. Delivering CF-wide capabilities as the new planning documents argue will provide the CF with greater operational flexibility; i.e., an effective technology insertion strategy will facilitate future enhancements to such operational flexibility while also mitigating the risks posed by system/sub-system obsolescence.

Undoubtedly, this new TI paradigm will have significant costs. Contract monitoring and enforcement, intellectual property concerns (when two or more suppliers are involved) and higher up-front expenses related to the use of higher risk technology and overall system complexity suggest that higher fixed costs (including design, development, deployment and support cost as well as contract related transaction costs) can be expected under this less risk-adverse approach. Moreover, if defence planners sought to procure an entire military platform (such as a major combatant surface ship) then a sufficiently capable defence industrial base possessing the knowledge, expertise and capacity to manage all aspects of a TI-enabled procurement strategy would be a necessary condition. In this respect then, the barriers to effective technology insertion may be particularly acute for militaries like the CF who are supported by a smaller defence industrial base and rely at least in part on cooperation with allies to develop major weapons platforms (the F-35 Joint Strike Fighter for example). As the growth in unit costs for platform procurement continue its inexorable rise, the ability of domestic industry to produce a sufficiently economical number of production units decreases (as does the government's ability to buy, to pay for such short production runs) which in effect means that not all the procurement one might wish to contract for may be domestically available.[24] It is therefore exceedingly risky to consider embarking on a "national project" type of commitment that would see Canada try to produce entire platforms at home with minimal support from allies.

4 The Practice of Technology Insertion: Canadian and Allied Perspectives

4.1 Technology Insertion and Capability Based Planning in Canada

The recent adoption of a Capability Based Planning (CBP) approach for the Canadian Forces represents a paradigm shift away from the tradition, Cold War approach of Threat Based Planning (TBP). TBP focused attention a single military threat—that posed by Soviet conventional forces—and sought to deliver the military capabilities intended to meet those very specific requirements typical of the high-intensity conventional warfare end of the conflict spectrum.

In contrast, CBP views the development of military capability as being a blend of people, process and materiel, for the intended development of an ability to execute a specified course of action along a much wider stretch of the conflict spectrum.[25] Moving away from platform-centric solutions, which tend to be the hallmark of TBP, CBP demands planners take a more holistic view of capability development, that is, viewing capabilities within a system of systems (SOS) [26] context and across a multitude of mission-types.

The procedural representation of defence systems acquisition within a Capabilities Based Planning approach can be understood as follows. As with any new acquisition of systems for the Canadian Forces, the Chief of Force Development retains responsibility for the acquisition decisions, which begins with a Capabilities Based Planning assessment. This process uses current government policy (as articulated by the Defence Policy Statement—DPS), guided by a forecast of the future security environment and a set of CF Force Planning Scenario documents, to define a set of capability goals that the CF believes will be required in a twenty-year time frame (approx. 2010-2030).[27] While the Joint Task List identifies the desired capability actions, Force Planning Scenarios provide context and missions boundaries. Desired capabilities are then grouped according to their tactical, operational or strategic operating environment thereby resulting in Capability Areas, for example C4ISR, Conduct Operations, Force Generation, Sustainment and Employment.

Additionally, this process provides for the identification of system capability deficiencies and thus defines an “as is” initial capability configuration which can be easily compared to a clearly defined “to be” end-state capability configuration. Under an Evolutionary Acquisition approach where end-state capability requirements are clearly defined, a system development roadmap can be constructed (with appropriate capability metrics) that will illustrate the process of system transformation from the “as is” to the “to be” state.[28] This procurement and system development method facilitates more effective optimization between systems and their intended operational employment (although a spiral approach may be more desirable if the breadth of anticipated force employment missions is rather wide, that is, if there is little certainty regarding what future environment(s) the system may be required to operate in).

CF capability goals are then prioritized in the Strategic Capability Roadmap (SCR) which is used by the Chief of Program (CPROG) to produce an Investment Plan which ties the SCR direction to an expected future funding forecast. At this point, projects can be prioritized, stood-up and

managed through the Defence Management System where program development can proceed through a step-wise plan including identification, procurement, acquisition and installation phases. Upon deployment, responsibility for life-cycle management is handed off to the Operational Weapons Systems Management system. This process is depicted below in Figure 4.

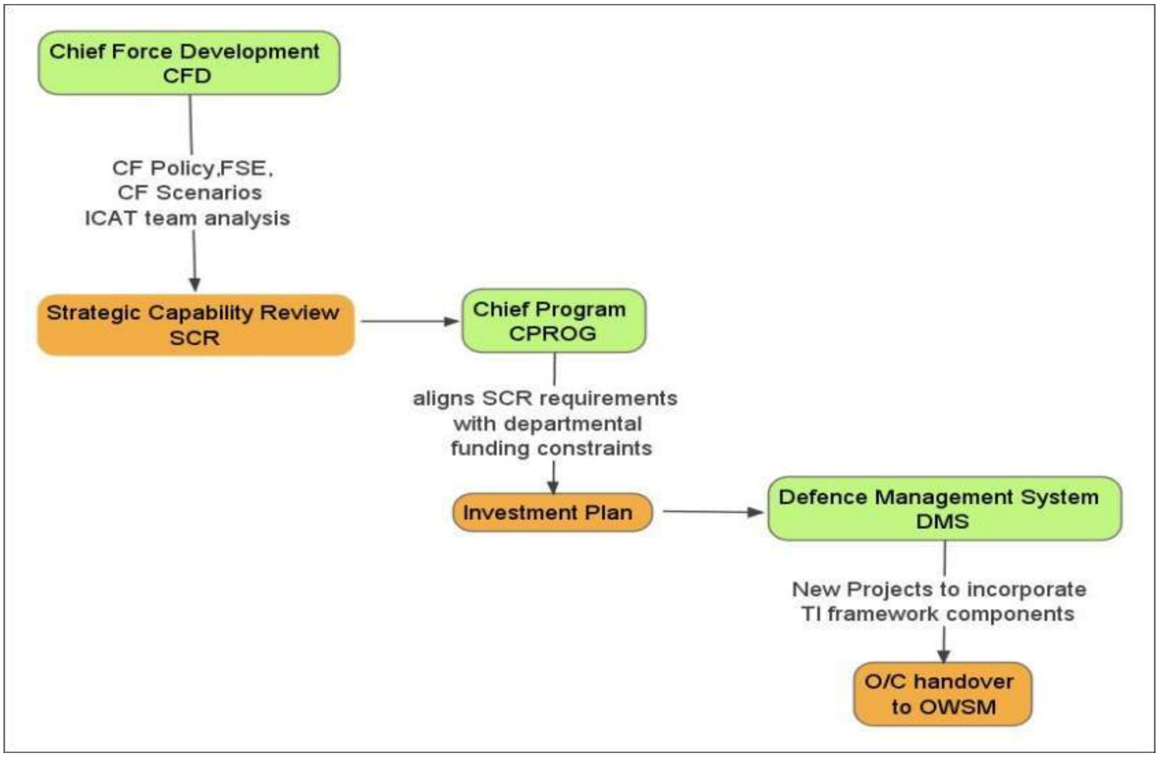

Figure 4 CF Force Development Process

An initial treatment of the Technology Insertion Concept of Operation for the CF was undertaken in April 2009. Not surprisingly, the report called attention to the CF current life cycle support process (as depicted in Figure 5) correctly noting that:

> Under the CF's current life cycle support process, an initial fleet fit of equipment is acquired and installed and a two year supply of spare parts is purchased and warehoused. From the initial installation then until the system is replaced, the capability inherent is the system is fixed and it begins to degrade with age as well as becoming obsolete with each advance in the field as shown. [29]

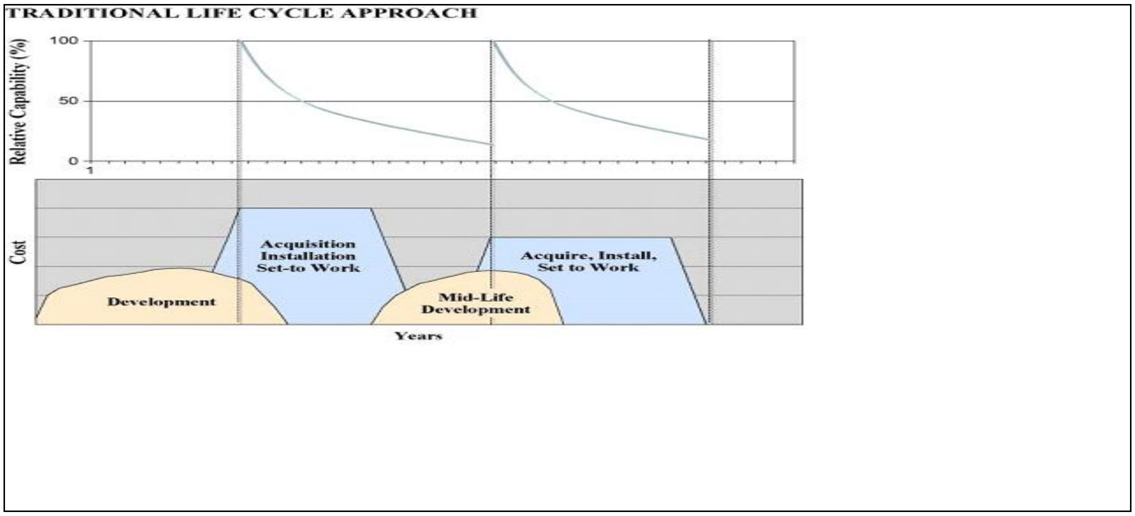

Figure 5 Traditional Lifecycle Support Process

The report went on to argue that adopting a TI philosophy towards lifecycle management would: (1) provide superior through-life capability performance, owing to a system design and installation method intended to make future upgrades more regular and seamless; and, (2) forestall those obsolescence risks associated with long-lead hardware and software development (see Figure 6).

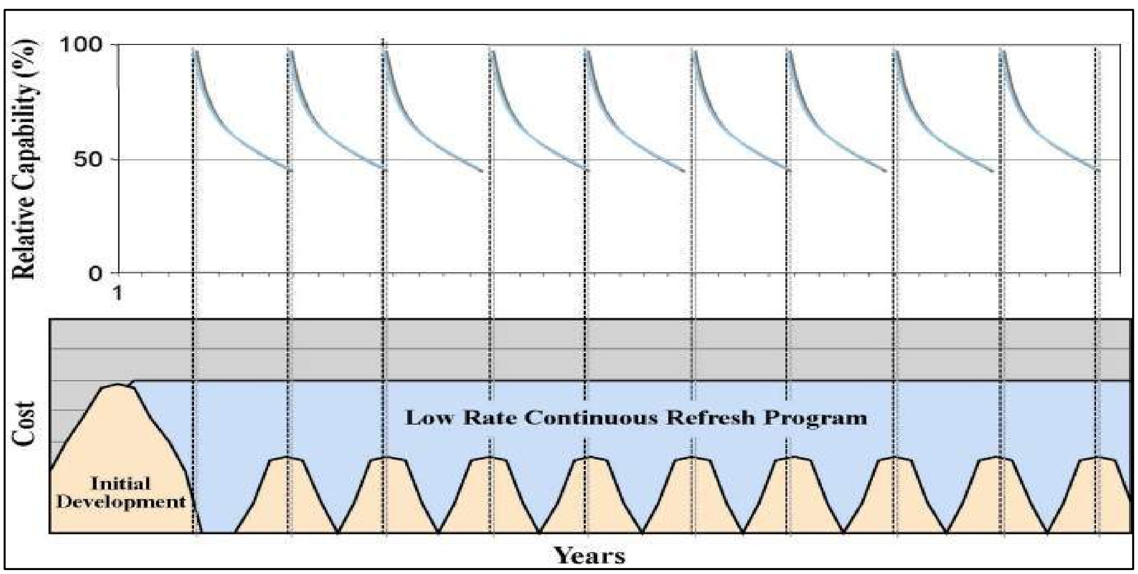

Figure 6 Lifecycle Management under Technology Insertion Process

The report concludes that a TI process could be introduced without great difficulty and would provide significant gains in terms of through-life operational effectiveness and mitigating obsolescence risk. While it is beyond the scope of this analysis to comment on the intricate management processes necessary for TI adoption, the CF Concept of Operations document does make several assertions which deserve further attention. Firstly, the report asserts that “no new money” would be needed to facilitate either the shift towards a TI centric management process or the necessary investment required at the outset of system, equipment, and component design. In fact, almost no literature discussing TI at the theoretical level ventures to estimate the costs of implementing such a program, unless the objective of the TI proposal is specifically intended to reduce the costs of ownership associated with a particular defence system. Secondly, the document expects “greater risk reduction due to smoothing effect of routine upgrades.” It is true that demand smoothing should lower funding volatility but it is unclear if sustained, higher spending levels (as TI would require) is a more desirable allocation of resources where maximizing “bang for buck” is the optimization problem. As some studies have suggested, albeit insufficiently, TI projects, like traditional acquisition projects of the past, tend to suffer from “conspiracy of optimism” behaviour which can result in unrealistic development and deployment timescales as well as overly optimistic risk and cost assessments.

That said, the advent of CBP for the CF, which explicitly encourages output-based planning by linking strategic goals to capability decisions, is a welcome development for advocates of TI. By focusing on forecasted future capabilities and the consequential effects, the tendency to simply upgrade existing systems can be avoided in favour of a more robust “cost-effectiveness analysis.” This model of capabilities analysis, which assesses procurement options in terms of their adequacy to deliver military capabilities as defined by the policy goals of the DPS, prioritizes competing options and awards program funds based on the value they provide. Here, resources can be transferred among various defence programs and across the services to ensure the most productive use of limited defence capital. The TI concept is thus well suited to implementation within a CBP process and will further CF goals as: (1) its primary focus is on the delivery of a maintained or enhanced capability; and (2) TI proposals are best presented as lifecycle management “options.” In terms of the former, the TI concept is in philosophical alignment with CBP as it too emphasizes capability development within a clearly defined operating space; and, in terms of the latter, owing to the innate specificity of their design and performance parameters, TI proposals can be compared against one another in a rather straightforward manner to determine if they satisfy the capability and cost-effectiveness criteria of the DPS.

4.2 Allied Perspectives on Technology Insertion

United Kingdom

A variety of Technology Insertion programs has been undertaken by several of Canada’s key strategic allies, specifically, the United States and the United Kingdom. The United Kingdom has taken the step of developing Technology Insertion into a major program area and intends to incorporate the TI approach into a broader procurement-industrial policy of complex systems engineering (COPS) and Short Lifecycle Acquisition (SL[A]). According to a recent U.K. Industrial report, there is a shift currently underway:

> Away from the traditional pattern of designing and manufacturing successive generations of platforms—leaps of capability with major new procurements or very significant upgrade packages—towards a new paradigm centered on support, sustainability and the incremental enhancement of existing capabilities from technology insertions. [30]

Like Canada, the UK sees four principal drivers that are elevating the prominence of Technology Insertion; these include: reduced defence budgets, less predictable future threat environments, requirement for extended operation lifetimes of existing and future systems, and the rapid pace of S&T advancement with concomitantly shorter lead times for R&D certification. Clearly, then, there is a requirement that technology be adopted into existing and planned systems so as to avoid a relative capability decline against enemies who may not possess extreme sophistication, but are nevertheless effective owing to their use of new enabling technologies. [31]

Among the U.K.'s Technology Insertion Major Program Area Studies, several key recommendations have emerged (some of which have been discussed above) for enabling effective technology insertion. Such themes include: ensuring design for maximum adaptability to new technology for easy technology insertion, which can be accomplished by using modularity and open architecture engineering methods; greater use of commercial off the shelf technologies, which can significantly reduce research and development phase technology risks while leaving one better positioned to exploit maturing, future technologies; shortening life-cycle upgrade intervals to more closely match COTS life-cycles, thereby enhancing through-life capabilities; using technology road-mapping techniques to maximize awareness of technology availability, maturity and suitability levels so as to reduce technical risks, smooth transition timelines (upgrade intervals), and minimize production phase complications.

The UK intends to implement the technology insertion concept within a broader SLA approach and has identified several potential platforms to serve as pilot projects; these include the Bowman radio, Tornado fighter, Sea King Helicopter, and the Next Generation Aircraft Carrier.

United States

In typical fashion, the United States' military is somewhat ahead of its allies in exploiting aspects of the technology insertion concept which it has done within a broader incremental or evolutionary based planning procurement architecture. Some notable programs developed under this rubric include the Predator UAV and Virginia Class Submarine program (discussed above). These programs were identified as ideal candidates owing to their requirement for cutting-edge technologies (which could be satisfied by mature and near-mature COTS) and to maintain maximum operational flexibility. Moreover, in the context of a spiral acquisition approach, where the end-state requirements are purposely left unknown to facilitate flexible capability development, effective leveraging of Technology Insertion allowed the Predator to rapidly adopt a land attack capability on top of its original intelligence, surveillance and reconnaissance capabilities (at the behest of U.S. commanders in Afghanistan and Iraq). Similarly, the Virginia class submarine fleet was adapted quickly to enhance its littoral, conventional land attack, Special Operations and ISR capabilities in response to the changing demands of the Global War on Terror (GWOT).

As well, and in response to Congressional inquiries, the U.S. DoD has initiated work into examining the benefits of inserting cost-reducing technology into its OMS regimes for pre-existing defence systems.[32] This effort is centered around a "spend money to save money" concept, where significant dollars spent on R&D in OMS work could potentially produce long-run benefits in terms of dollars saved in reliability and maintainability (see also, 5.2—Cost of Ownership). Return on investment (ROI) savings have been reported to be very significant, and stem from some rather unsophisticated though plainly obvious uses of new systems (sub-systems and individual components) and maintenance procedures.[33]

For Canadian defence planners, surveying allied practices is a necessary step in evaluating whether or not technology insertion is appropriate for the CF. Admittedly, the body of work in this field is not large, although the well-resourced work done by the U.K. in partnership with defence research contractor QinetiQ is impressive in its scope and timeliness.[34]

Deserving particular attention was the work of Jobson (2008) which ably covered the TI question from the broader perspective of SL acquisition, no doubt suggesting the two issues be discussed as complementary concepts. However, the absence of any analysis relating to costing (beyond the theoretical or anecdotal) is troubling and is indicative of a general dearth of analysis in the translation of TI from theory to practice. As well, there was little discussion of a cost-benefit assessment of various TI proposals, an exercise one would have to undertake to determine the expected value gained by the warfighter.

Quite oppositely, most U.S. literature on TI tended to focus on the practical application of TI to defence procurement and lifecycle management. Having moved beyond a theoretical discussion of TI the DoD has seemingly embraced TI as a pillar of its evolutionary-spiral approach to major weapon systems acquisition. Both Hutchison (1996) and the CBO Budget Analysis utilized a case study approach to highlight the potential benefits of TI, primarily from an obsolescence and cost of ownership risk perspective. Although both studies are perhaps somewhat dated, other sourced literature provided current analysis of TI programs currently underway in deployed systems (such as Predator and the Virginia Class submarine program).

It would be of great value to Canadian defence planners to stay well informed and keep abreast of TI related developments in both the United Kingdom and the United States. Because of their "head start" in this and other related fields, Canada is in the enviable position to analyze both the success and failures of our allies' efforts to institutionalize TI as a pillar of acquisition and lifecycle management policy. It is likely that we will quickly discover, based on the experience of our allies, which TI projects are feasible in Canada and which are not (by virtue of technology risk, industrial capacity, and overall program cost). Nevertheless, the existing allied literature on technology insertion is on balance convincing, which therefore suggests that DND begin a more forceful exploration of TI for the CF.

5 Optimization for Technology Insertion: Cost-Benefit Analytic Methods

In order to assess the utility of a TI-centric SL approach to defence procurement, a variety of merit criteria needs to be established. Roughly speaking, these are cost-benefit type criteria which offer a generalized equivalent valuation where the costs and benefits (in terms of capability, cost of ownership and obsolescence risk) of a TI-enabled platform are compared to a non-TI-enabled platform. Some work has already been done in this field by our U.S. and U.K. counterparts, so it should be a relatively straightforward exercise to adapt some of these metrics for the Canadian case. The following section provides an overview of useful metrics which can be used when deciding for which of the principal three variables (capability, cost of ownership, or obsolescence risk), one wishes to optimize TI. More detailed cost forecasting and cost-benefit techniques will be explored in the subsequent quantitative study.

5.1 Optimizing for Capability

When one wishes to address the cost-benefit criteria necessary for the consideration of a TI upgrade option aimed at maintaining or enhancing system or subsystem capability, the first significant action to be undertaken is to understand the existing system and thereby establish an "as is" baseline for capability performance and its associated cost level. This can be likened to the "do nothing" option, that is, to continue with current performance levels (which are likely to decline over time) to the end of its service life. In such a case, the likely risks of a capability shortfall are high and significant. Doing nothing, therefore, is not likely to be a realistic proposition. Knowledge of the system's baseline characteristics, the various TI options being proposed and their potential interplay between the two is essential in identifying accurate cost-benefit relationships.

The output from a baseline assessment includes two aspects: benefit and cost. Baseline "benefits" should be measured in terms of the capability effectiveness of the baseline system. If baseline capability already shows signs of a capability shortfall, then the capability gap, as measured against the required capability (or the potential TI-enabled capability), may be quantifiable which would facilitate a straightforward comparison. As well, a TI option may have both core and additional benefits (and detriments). These too must be considered in a value-for-money analysis and ought to be weighted accordingly.

Baseline costs refer to the forecasted costs to continue operation and support of the baseline system and should include such others as whole life-cycle costs (fixed, variable and threshold), such as those associated with upkeep, mid-life upgrade, parts replacement, etc., necessary to preserve some credible level of capability.

Combining these two aspects, one can compare the cost-benefit potential of a TI enabled system against that of the baseline: the maximum Cost–minimum Benefit threshold seen in Figure 7. As well, we can compare various TI options against one another to develop a basket of options and compare those upgrade options against the baseline threshold which can also be understood as the minimum benefit (capability) and maximum cost level one is willing to accept in an upgrade option.

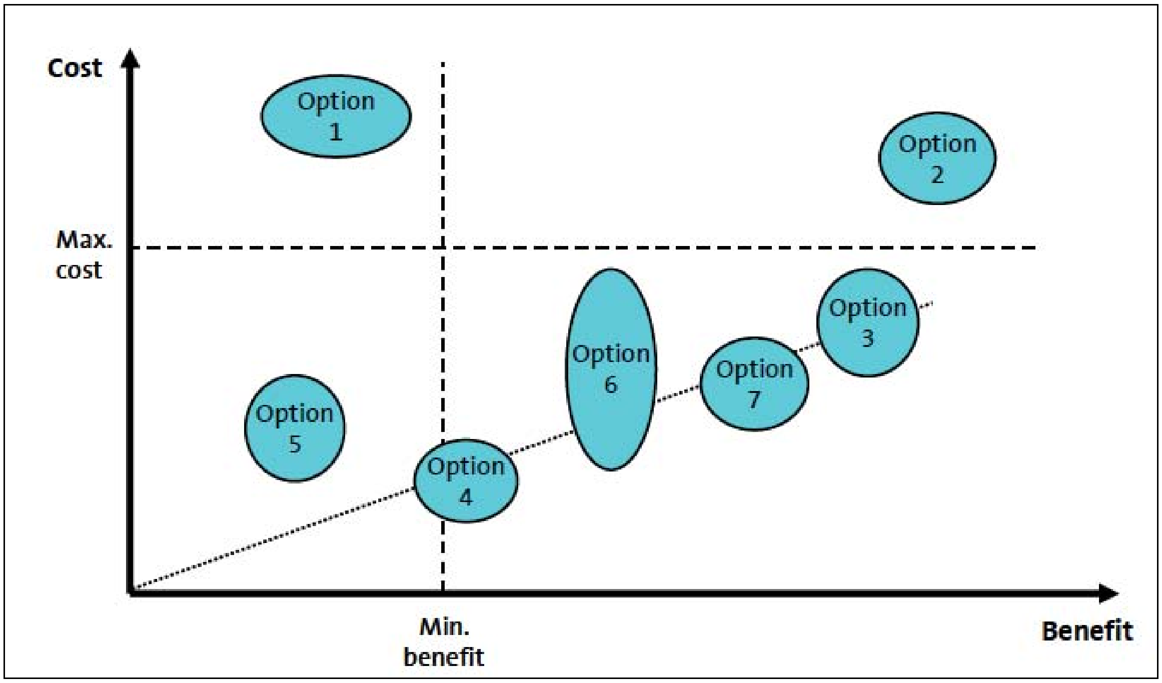

Figure 7 Cost-Benefit Comparison Chart with various TI options. [35]

Facing such a cost-benefit plot, the decision-maker could then select a TI option, likely keeping to the following logic:

- Options 1 and 2 may be excluded as both are above the maximum cost threshold;
- Option 5 may be excluded, as this is below the minimum benefits threshold.
- Option 4 presents a difficult problem for the decision-maker, as it has a relatively low cost, but has a significant risk of not delivering the required benefit. If the 'benefit' uses a relatively softer metric definition, it may be worth accepting risk for the lower cost. However, if the minimum benefit is a hard limit, the level of risk associated with Option 4 may be unacceptable, leaving only Options 3, 6, 7.
- Option 3 may be regarded as the best option because of the higher benefits it delivers.
- Alternatively, Option 6 may be chosen as the best option, if the risks can be managed so as to ensure that costs are kept within the lower part of the shaded area, and thus lower than the most likely costs for Option 3.
- It is also possible to choose Option 7, which may be regarded as striking a better balance between benefits and cost, and delivers a higher benefit-to-cost ratio.

Identification of an option's risk, that is, risks which may develop due to cost or schedule slippage, design-production concurrency, unforeseen technical challenges, and use of immature or near mature technologies must also be properly analyzed and weighted to the TI option in question. As the risks with a particular option grow, the size of its footprint would increase and stretch, vertically or horizontally, to illustrate higher potential cost and performance risks as well as wider confidence intervals. Moreover, the extent of change (design impact, logistical effects) involved in exercising a TI option is often significantly underestimated and increases as system/component and system/platform interactions become more complex (the predominant

feature of modern defence systems). Emergent properties risk, that is, the degree to which actual system behaviour differs from expected system behaviour, can be equally dangerous and just as difficult to foresee.

5.1.1 The Real Options Analysis Approach

As discussed throughout this Memorandum, it may not be possible to specify all or some of the future system requirements accurately or completely because of the inherent volatility and uncertainty of technological development and mission scenarios. Use of the traditional requirements process, where procurement managers set very specific performance parameters against which the system is costed, designed and produced, cannot satisfy the now overriding need to achieve maximum system flexibility. A more dynamic and responsive procurement system demands that the requirements capture-and-analysis phase be on going throughout the life of a system. Continual feedback from the system's users has the advantage of informing technology plans and de-risking future system increments because deviations from users' expectations are identified early and users are able to refine and validate less mature requirements based on their experience with the system's early instantiations.

This "options generation" phase is also likely to produce new or additional requirements, which could enhance system capability or reduce costs. While such innovations are valuable, they can also contribute to "requirements creep" in the system's design-production phase, potentially resulting in project delays and cost increases. Therefore, a tool is required to enable rapid assessment of lifecycle impacts stemming from evolving user requirements and technological developments.

For procurement officers operating with a limited budget and limited information, the key is to identify the value of each option and understand how much should be invested in building each option into the design. This equates to determining how much should be spent "buying" each option at project birth. The officer faces a classic production constraint in that the more money invested in building one option, the less the officer can invest in incorporating other options.

A most promising analytical tool for comparing future options is a methodology known in financial circles as "Real Options Analysis" (ROA). The chief draw of ROA lies in its ability to provide a framework for quantifying whether the cost of additional flexibility in a project represents value for money (by capturing it explicitly within the project's Net Present Value (NPV)). Financial Options allow traders to enter into an agreement in which they have the right but not the obligation to buy or sell assets at a future date at a predetermined price (known as the Strike Price). The trader pays a fee (the Option Cost) to be able to have this option guaranteed at (or up to) a certain point in the future, thereby acting as a kind of insurance against uncertain conditions prevailing in the financial asset market.

Adapting this concept for use in defence procurement is a relatively straightforward task. Gil defines the design and physical development work needed to ensure, or enhance, the embedding of a real option into the design phase as a "safeguard", and the capital spent in "safeguarding" an option (i.e., ensuring that an option stays efficiently open), as the option's cost. The decision to "safeguard" each option from a portfolio of options hinges on two determinants: (1) the assumed uncertainty as to whether or not the option will be exercised in the future, and (2) the modularity

of the system's design in which to embed the option.[36] It then follows that the attractiveness (or demand) for safeguarding goes up when the assumed uncertainty that the option will be exercised is low (in other words, there is a high likelihood that the option will be exercised). Low uncertainty is often associated with options that are likely to be exercised in the short-term because the likelihood of the future diverging from scenarios foreseen upfront increases as time progresses. As well, when design modularity is assumed to be high, the benefits derived from "safeguarding" increase.

Trigeorgis identifies other variables which affect real option evaluation: (1) the value of the underlying asset, i.e., an asset with the same risks as the project that the firm would own if the option was exercised; (2) the cost to exercise the option; (3) the time to expiry of the option; (4) the volatility of the value of the underlying risky asset; and (5) the "riskless" interest rate over the life of the option.[37] Therefore, the larger the NPV of a project, the greater are the potential losses from making an irreversible investment decision and, therefore, the greater the potential option value. Equally, the greater the volatility and the longer the period of delay given by the option, the more the option is potentially worth because the range of possible outcomes under which it will be profitable to exercise it will be increased as a result. ROA can therefore be seen as a form of insurance, and since a certain outcome is generally preferable to an uncertain outcome, the procurement organization would be willing to pay more to maintain flexibility as the risk increases. Thus, as the present value of the option increases or the volatility increases, the value of the option increases and so the organization would be willing to pay a higher option cost.

5.2 Optimizing for Cost of Ownership

As explained in previous sections, major interest in Technology Insertion comes from its potential for savings generated by the insertion of effective cost-reducing technologies into platforms already in the deployment phase of their life-cycle. Central to this rationale for TI is the use of technology to enhance a system's reliability and maintainability. The effect of this will drive down OMS's burden on the overall program budget. As is the case with modern complex defence systems, OMS costs invariably exceed those of the procurement phase.

To determine the potential for savings, a Return on Investment (ROI) metric can be used to calculate the potential returns derived from the investment of inserting a cost-reducing technology. A feasibility study contracted by the U.S. DoD drew data and case studies from across the Services and extrapolated potential savings over a 10, 20 and 25 year life-cycle time horizon. The observed trend suggested savings in operating and maintenance cost can vary widely, but tends to increase the longer the timescale one considers. The study found an average or break-even level of 9 times the initial insertion cost was achievable for the program candidates submitted by the various Services.[36] It would be up to decision-makers to determine what cost-savings multiple level constituted their tolerance threshold, and while this would almost certainly have to be done on a case-by- case basis, the ROI statistic does allow for a common method of computation.

The model defines ROI as Savings divided by Cost of Investment. More specifically:

- Savings = (Cost of operation with existing approach) – (Cost of operations with the cost-reducing technology implanted).

- Cost of Investment = (Summation of costs of development [i.e., tailoring of technology to weapon system application], integration, testing, production, and fielding of upgraded weapon system). Sunk costs are not included.

As well, the ROI metric is computed with and without field personnel costs, since any labour hour reduction may not result in Department-wide personnel cost reductions. In many situations, labour hours freed up on a specific weapon system are applied to other Department labour requirements. Thus, it is important for the decision-maker to know the magnitude of the personnel component of savings when evaluating an investment decision. Discount rates were also applied to future savings and investment to provide an appreciation of the time value of money over the periods in question. A cross section of cases within the study is presented in Figure 8 to demonstrate the model and provide a sample of its findings.

Project description	Investment ($ million)	10 year saving ($ million)	10 year ROI (# to 1)	20 year savings ($ million)	20 year ROI (# to 1)
Composite repairs of C/KC/RC-135 aircraft cracked and corroded structure	0.1	6.9	69	12.3	123
M-9 ACE — crew vent fan replacement	0.01	0.3	25	0.4	44
Integrated petroleum, oils, and lubricant data system	0.6	11	20	21.6	39
M1A1 tank — M256 120mm cannon tube and breech life extension	0.8	12.6	16	20.7	26
Solargizer vehicle battery maintenance system	5.8	81.8	14	140.6	24
A-10 aircraft — embedded GPS INU (EGI), versus AF baseline A-10 configuration with LN-39 inertial system and A-3 GPS receiver	8.9	105.7	16	235.2	35
MLRS fire control panel troop proficiency trainer (FCP-TPT)	3.2	36.4	11	0	10 year life
AH-64 helicopter — pressurize hydraulic reservoirs during aircraft startup and remove reservoir check valves	0.5	2.7	6	13.1	26
AH-64 helicopter — engine nose gearbox, change to cartridge-type oil pump	0.2	0.2	0	0.8	4
Total	20.1	257.6	13	444.7	22

Figure 8 Sample ROI of selected programs

5.3 Optimizing for Cost of Ownership

To optimize TI to counter system or subsystem obsolescence risk, two factors are of particular importance, namely, Technology Maturity and Technology Suitability (other nomenclatures use readiness in place of maturity or receptivity instead of suitability). To minimize technical risks associated with a TI program, whether that program is the replacement of a sub-system or the

development of an entirely new platform, decision-makers can employ a variety of tools to assess technology feasibility and to facilitate the technology transition process.

Tools which are used to assess the maturity and readiness of technology for TI include: technology forecasting, technology road-mapping, and the use of Technology Readiness Level (TRL) indicators.

In order to exploit state of the art technologies, it is essential to have and maintain a technology awareness capability, often referred to as Technology Watch(ing) or Technology Forecasting (or Foresight). This tool aims to forecast and determine dates and probabilities of scientific and technological breakthroughs as well as their probable impact. For example, the U.S. “Air Force 2025” study sought to identify the concepts, capabilities, and technologies the Air Force would require in its F-35/JSF program to retain its preeminent airpower position. The study found ten capabilities and eight high-leverage technologies as the best investment candidates to ensure future capability.

Technology Roadmapping is a process used to identify, select and develop technology options for future operational needs. It allows an organization to identify critical product needs that drive technology selection and investment decisions. As well, roadmapping assists in identifying and selecting appropriate technology alternatives, and driving implementation planning, by specifying what levels of technology performance are needed and at what time.

TRLs are effective technology management tools which are in wide use in U.S. civilian and military spheres.They provide a structured means of measuring the maturity of technologies being considered for procurement programs and are used to assess the risk and the use of alternative technologies for a particular system, sub-system or platform. A numerical value is assigned to each readiness level; typically, 1-3 refer to technology development and levels 4-9 relate to maturation of design application. (See Appendix 1 for a TRL template adapted for use by U.S. National Aeronautics and Space Administration)

Effective use of technology forecasting, roadmapping and TRLs have reduced the technical risk factors facing the JSF prior to the commencement of the engineering and manufacturing development stage (see, for example, figure 9).

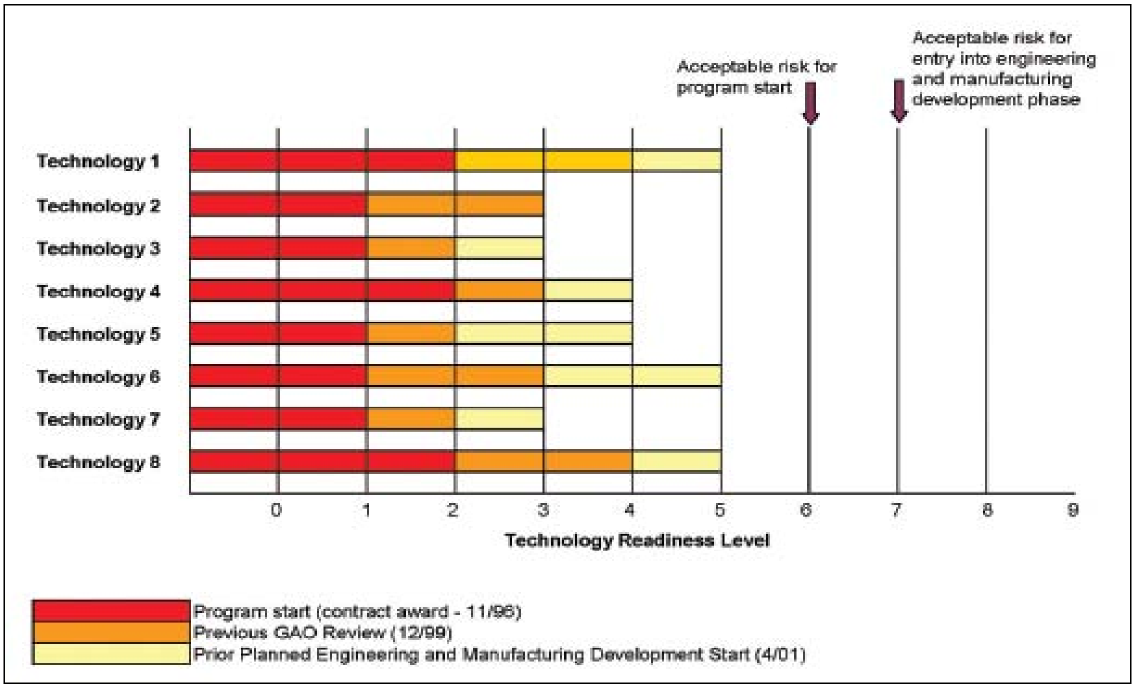

Figure 9 Actual and Projected Joint Strike Fighter critical technology readiness levels.

Similarly, there are several tools available for evaluating the suitability of technologies for insertion. Four such mechanisms employed widely among Western militaries are: Simulation Based Acquisition (SBA), Test and Evaluation (T&E), Technology Demonstration Programs (TDPs) and Rapid Prototyping.

SBA is widely used by the U.S. DoD throughout the acquisition process to provide a robust analysis of system performance in the operating environment in which it will be used in the closing evaluations phases. SBA also provides for an assessment of the effect of specific equipment or capabilities on battle outcomes. Use of SBA can reduce the time, resources and technical risks associated with the acquisition process and it can increase the quality, military worth and supportability of fields systems while reducing total ownership costs throughout the whole life-cycle of the system.

T&E is an essential component of the systems engineering process especially under evolutionary and spiral development regimes. T&E is critical to producing and improving overall systems by integrating knowledge about the impact, as well as the benefits and limitations, of each technology insertion in the development cycle. Coupled with the use of rapid prototyping, which can shorten and smooth the transition between development and production phases, T&E can

reduce risks of cost (un)reliability, operator safety, general system performance and effective satisfaction of user requirements.

TDPs are mechanisms for demonstrating and validating concepts based on new or emerging technologies through testing. These programs are designed to speed technology maturation, assessment and facilitate the transition of advanced technologies. The mechanism also allows for iterative improvements or “upgrade bundles” to progressively introduce new capabilities according to technological maturation timelines, mission requirements and budget availability. Successful TDPs support quicker transitions to the procurement phase of a program with a more complete understanding of eventual system performance characteristics.

6 Conclusions and Future Directions

The preceding Memorandum was a strategic-level, qualitative literature review of the TI philosophy and, ultimately, its feasibility for adoption by DND and the CF. The goal of this initial project was fourfold: (1) to develop a theoretical understanding of technology insertion; (2) to develop an appreciation of the enablers and impediments to operationalizing technology insertion; (3) to seek out "best practices" derived from work already undertaken by some of Canada's key allies; and (4) to identify the cost-benefit criteria necessary for assessing the feasibility and suitability of TI proposals.

Although definitional issues persist, it is widely agreed that TI refers to the "refreshment" and "enhancement" of system performance and functionality in existing or deployed defence systems by the utilization of a new or improved technology. Importantly, TI in defence systems can occur in the vertical space—which constitutes components, equipment, sub-system, and the system level—and the horizontal space—which finds common solutions to similar but distinct weapons platforms, such as land systems. It was strenuously noted also that engineering design concepts such as Open Architectures, COTS and modularity do not constitute technology insertion activities in and of themselves; rather, such design concepts are enabling elements of complex systems engineering, which among other things, can facilitate the employment of TI once a system has entered service.

As a mechanism for managing system or sub-system obsolescence, to reduce "costs of ownership" associated with a particular defence system or, as we are primarily concerned with in Canada, to maintain or enhance a system's capabilities and unit-force effectiveness throughout its lifecycle, the concept of Technology Insertion is undoubtedly in its ascendance. Ideally, technology insertion activities would occur within a broader procurement program which stressed flexibility and is resourced for greater risk-taking. Both flexibility and risk-taking are key features because militaries of today are increasingly being called upon to conduct non-conventional operations (such as counterinsurgency) while in disparate geographic environments. In such circumstances, operational requirements are dynamic and therefore require a more responsive procurement and support program. As well, risk-taking in terms of technology developed and deployed by industry needs to be encouraged because even an unsophisticated enemy can employ a modern commercial technology to gain tactical advantage on the battlefield if the warfighter is stuck with antiquated equipment. Therefore, both the defence bureaucracy and the industrial base need to be properly incentivised to incorporate flexibility and risk-taking into their requests and proposals of TI-enabled procurement programs.

To that end, force development under CBP stands to benefit from greater integration of the TI concept with the Evolutionary Acquisition approach. This is so because EA seeks to deliver capabilities in increments and in full recognition of the need for future improvements in future capability. TI and its associated technology management mechanisms seem ideal for facilitating future upgrades where end-state requirements may (but more likely may not) be known. It can be argued that such an approach relies too heavily on the vicissitudes of technological innovation in the civilian sector. However, for a small country like Canada, this technological volatility risk may be less than those of the requirements volatility of the "user" community. And while there exist mechanisms for monitoring, managing and maturing evolving civilian and defence

technologies, no such corollary exists in regards to satisfying the always dynamic, always highly specific, requirement needs of the military.

As our allies experience with nascent TI programs demonstrates, substantial gains in terms of greater operational currency and a reduced logistical burden are possible if technology insertion is effectively implemented. Curtailing the costs of ownership of a particularly burdensome defence system represents the “low-hanging fruit” which can likely be attained with moderate effort. Optimizing technology insertion for this purpose ought to be considered a strong candidate for the first of any future Canadian pilot project. As well, having the benefit of hindsight of our allies’ TI programs, DND should look to develop a subsequent pilot program which allows a vertical technology insertion program to develop in one of its key, high-use systems such as the LAV-III. VTI seems ideal for our purposes as the nascent program would start with a low risk, component level assignment and, if successful, would allow for a gradual progression towards more complex TI at the equipment, sub-system and perhaps ultimately at the system level.

In the final section of this Memorandum, an overview of various analytic methods germane to the optimization of TI was provided. Whether seeking to manage technology maturity risk or maximizing returns on OMS investment, defence planners require a robust cost-benefit framework if they are to accurately assess the potential value of a technology insertion program. Therefore, before DND and the CF can embark on an experimental pilot project, there is a clear need for more work to be done in the area of developing such cost-benefit models. Specifically, greater clarification of what constitutes costs (financial, manpower and other capital requirements) and benefits (operational flexibility, logistical burden, etc.) and how these factors change over time is needed. Delivering a convincing business case will depend heavily on the development of a more robust cost-benefit methodology.

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Annex A Technology Insertion Defintions

Table 1 Technology insertion definitions

Author(s)	Definition
Britt [5]	The introduction of a new technology to the system
Dowling and Pardoe [6]	The insertion of a subsystem (or equipment) that implements and reifies the new technology
Dowling and Pardoe [6]	The act of integrating the new subsystem into an existing, receiving system and harmonizing the interactions between the system and the subsystem to raise the overall capability
DPA [4]	That aspect of technology transition which concerns the management of the embodiment of technology in programmes beyond Main Gate
DPA [4]	The process of incorporating and exploiting new, or improved, technology into existing platforms, systems, and equipment
DPA [4]	The timely and affordable adoption of appropriate technologies, both software and hardware, in receptive weapons, platforms, and systems that will allow the continual and progressive enhancement of capability, availability, and supportability within those systems
DPA [4]	The identification, evaluation, and adoption of appropriate technologies for meeting capability, cost of ownership, and supportability objectives with respect to existing defence systems
Hobbs [7]	The insertions of new technologies into existing weapon systems
Hobbs [7]	The positioning of a new or current technology assemblage into an existing system to improve the overall system's capabilities
Kobren [8]	The process of applying critical technology in military systems to provide an effective weapons and support system in the quantity and quality needed by the warfighter to carry out assigned missions and at the best value as measured by the warfighter
Lucas [9]	The facilitation of inserting new technology advancements into later production lots to avoid or mitigate the problem of technological obsolescence
Mathaisel and Comm [10]	Incorporation of new or emerging technologies
US Army [11]	The alteration, conversion, or modernization of an end item which changes or improves the original purpose or operational capacity in relation to effectiveness, efficiency, reliability, or safety of that item

Figure 10 Various Technology Insertion Definitions

Annex B Technology Readiness Levels

Technology Readiness Levels and examples

Technology Readiness Level	Description
1. Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be evaluated for military applications. An example is paper studies of the basic properties of materials (eg, tensile strength as a function of temperature for a new fibre).
2. Technology concept and / or application formulated	Invention begins. Once basic principles are observed, practical applications can be postulated. The application is speculative and there is no proof or detailed analysis to support the assumptions. Examples, which are still limited to paper studies, include potential applications of new materials for thin film devices (eg, SIS mixers).
3. Analytical and experimental critical function and / or characteristic proof-of-concept	Active research and developments are initiated. Analytical studies and laboratory studies to physically validate predictions of separate elements of the technology are undertaken. An example is determination of the phase/temperature/pressure for a slush or super-cooled hydrogen propellant for a High Energy Density Matter propulsion concept.
4. Component and / or breadboard validation in laboratory environment	Basic technology components are integrated. This is relatively 'low fidelity' compared with the eventual system. An example is the demonstration of a new 'fuzzy logic' approach to avionics involving testing the algorithms in a partially computer-based, partially bench-top component (eg, fibre optic gyros) in a controls lab using simulated vehicle inputs.
5. Component and / or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. An example is use of a new type of solar photovoltaic material promising higher efficiencies in an actual fabricated solar array 'blanket' that is integrated with power supplies, supporting structure etc. and tested in a thermal vacuum chamber with solar simulation capability.
6. System / subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system is tested in a relevant environment. An example includes flight testing of a working sub-scale (but scalable) model of an innovative high temperature / low mass radiator involving liquid droplets and composite materials on a Space Shuttle or International Space Station 'pallet' (where microgravity, vacuum and thermal environment effects will dictate the success / failure of the system.)
7. System prototype demonstration in a space environment	Prototype near or at the scale of the planned operational system and is tested in an operational environment. An example is the Mars Pathfinder Rover, which is TRL 7 technology demonstration for future Mars micro-rovers based on that system design.
8. Actual system completed and 'flight qualified' through test and demonstration (ground or space)	Technology has been proved to work in its final form and under expected conditions. In many cases this TRL represents the end of true system development. An example is the successful loading and testing of a new control algorithm into the onboard computer on Hubble Space Telescope while in orbit.
9. Actual system 'flight proven' through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. An example is small fixes / changes to address problems found following launch such as the integration of new technology (such as a new artificial intelligence tool) into operational mission control at JSC.

(Adapted from White Paper, April 6 1995, John C Mankins, Advanced Concepts Office, Office of Space Access and Technology, NASA and GAO / NSIAD-99-162, July 30, 1999.)

Figure 11 Technology Readiness Levels

Annex C Alternative Acqusition Models

	Single Pass (CADMID)	Evolutionary	Incremental	Short Lifecycle
Requirements	Known at project start and remain relatively stable throughout the project	Overall requirements broadly understood for lifecycle and well understood for current phase	Known at project start and remain stable throughout lifecycle	Requirements for initial phase well known, future phases may be unknown
Design	Determined early	Architecture design and initial functions determined early; detailed design evolves through life	Determined early	Determined early and rapidly
Technology insertion	None planned from the outset	Opportunistic TI using recently matured technologies (including COTs)	TI planned using known maturing technologies (including COTS)	No TI into system but rapidly technology refresh achieved through incorporating recently matured technologies into replacement system
Delivery	Single delivery	Phased delivery	Incremental delivery	Multiple deliveries
Acquisition costs	Known and approved at Main Gate for entire system	Known and approved at MG for first delivery phase only. Each subsequent phase costed and approved separately. May have overall approval at programme level with capped costs	Known and approved at MG for all planned increments	Known and approved at Main Gate although may be able to obtain a programme level approval for a series of planned replacements
User involvement	Relatively low	High level of user feedback required to shape requirements for future phases	Relatively low	High level of user feedback required to shape requirements for future phases

Figure 12 Comparison of Alternative Acquisition Models

(Based on Henderson and Gabb [39])

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List of symbols/abbreviations/acronyms/initialisms

CBO	Congressional Budget Office
CBP	Capability Based Planning
CF	Canadian Forces
CORA	Centre for Operational Research and Analysis
COTS	Commercial Off The Shelf
DND	Department of National Defence
DoD	Department of Defense (United States)
DRDC	Defence Research & Development Canada
EA	Evolutionary Acquisition
FY	Fiscal Year
GDP	Gross Domestic Product
GWOT	Global War on Terror
HTI	Horizontal Technology Insertion
JSF	Joint Strike Fighter
MLU	Mid Life Update
NPV	Net Present value
OMS	Operations, maintenance and support
PPP	Private-Public Partnership
R&D	Research & Development
SBA	Simulation based Acquisition
SCR	Strategic capability Roadmap
SLA	Short Lifecycle Acquisition
SOS	System of Systems
T&E	Test and Evaluation
TI	Technology Insertion
TDP	Technology Demonstration Program
TRL	Technology Readiness Level
VTI	Vertical Technology Insertion

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Growing interest among Canada's allies in the field of Technology Insertion suggests a paradigm shift is underway in the way in which militaries develop and employ technology for use with their defence systems. Drivers such as a dynamic future security environment, rapid technological innovation and rising unit cost growth can significantly erode the combat effectiveness of deployed systems over the length of their lifecycle. Achieving optimal through-life capability effectiveness, lowered costs of ownership and a minimized risk of system obsolescence are three primary goals for which Technology Insertion can be optimized. This Technical Memorandum investigates the theoretical concepts of Technology Insertion, its practice among Canada's allies and, finally, provides some methodological tools necessary for an optimization-based, cost-benefit analysis of Technology Insertion options.

L'intérêt croissant des alliés du Canada pour l'insertion technologique semble indiquer qu'un changement de paradigme est en cours dans la façon dont les militaires élaborent et emploient la technologie à utiliser avec leurs systèmes de défense. Des facteurs, tels qu'un futur environnement de sécurité dynamique, l'innovation technologique rapide et la progression des coûts unitaires, peuvent éroder considérablement l'efficacité au combat des systèmes déployés au cours de la durée de leur cycle de vie. L'atteinte de l'efficacité optimale des capacités sur la durée de vie, la baisse des coûts de propriété et une limitation du risque d'obsolescence des systèmes sont trois des principales raisons pour lesquelles on peut optimiser l'insertion technologique. Le présent document étudie les concepts théoriques de l'insertion technologique et son utilisation parmi les alliés du Canada et fournira certaines méthodes qui sont nécessaires pour faire une analyse coûts-avantages fondée sur l'optimisation des options en matière d'insertion technologique.

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